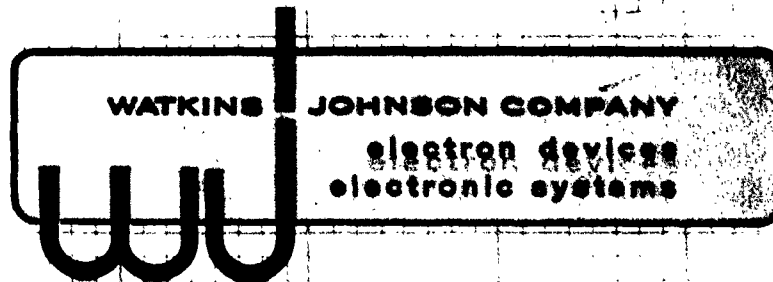


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REPORT NO. 7
DEVELOPMENT OF A MILLIMETER
LOW-NOISE TRAVELING-WAVE AMPLIFIER
1 June 1962 through 31 December 1962
U. S. ARMY ELECTRONIC RESEARCH
AND DEVELOPMENT LABORATORIES

Contract No. DA 36-039 SC-87384

Project No. 3G19-03-001-04

File No. W-J 63C-339R26

25 January 1963

By

E. W. Kinaman

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Prepared for
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MAY 9 1963

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PURPOSE

This report reflects, for the period covered, the continuing research and development activities by Watkins-Johnson under U. S. Army Signal Corps Contract No. DA 36-039 SC-87384, towards the development of a millimeter low-noise traveling-wave tube amplifier. Three such amplifiers, with focusing structures, will be furnished as contract end-items.

Watkins-Johnson is currently working on development of a somewhat similar amplifier for E-band, under U. S. Air Force Contract No. AF 30(602)-2422. When state-of-the-art advances occur on either contract effort, they will be applied as a matter of course to the other.

ABSTRACT

This report details the current project status, as well as the development work occurring during the period June 1 through December 31, 1962.

The previous report (Quarterly No. 6) detailed the excellent focusing along with 30-40 db of electronic gain noted for tube No. 3.

This report details the improvement in circuit and waveguide components toward reduced loss in preparation for tube No. 5. This tube, assembled with a helix of .32 db/ λ g loss, provided the first observed over-all gain of 5 decibels at 80 Gc. Circuit deterioration, from abnormal beam interception, prevented noise figure measurements.

PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES

During the period covered the following personnel visited Watkins-Johnson Company regarding the status of the project:

August 1, 1963	Frank Kavanaugh (USAERDL)
September 25, 1963	Frank Kavanaugh (USAERDL)
October 16, 1963	Frank Kavanaugh, Arthur Gottfried (USAERDL)
November 26, 1963	Colonel Bruce Lindsey (ARPA)

FACTUAL DATA

Review

The previous report (Quarterly No. 6) detailed the achievement of 30-40 db electronic gain. Poor waveguide-to-helix coupling prevented the attainment of over-all gain. Tests on this tube showed adequate emission, and excellent focusing.

Summary

During the present period efforts were first devoted to reducing incidental losses and improving the coupling to the helix. Following this, tube No. 5 was fabricated with improved components. Tests showed five decibel over-all gain at 80 Gc. Adequate gain for noise figure evaluation would have been obtained had the circuit not deteriorated from abnormal beam interception. Preparations for the next and subsequent development tubes were directed toward circuit protection and increased tube gain.

Loss Reduction Program

Measurements on tube No. 3 pinpointed an excess loss problem. Waveguide-to-helix coupling appeared poor, perhaps ten decibels, circuit loss was high (in the order of .45 db/ λ_g), and non-predictable losses were experienced in the input waveguide and window assemblies. Accordingly a loss reduction program was initiated to bring these variables in control.

Excess Waveguide Loss

Through tube No. 3, the input waveguide was machined in the copper block. The assembly was completed by brazing the top waveguide wall in place. Even though the wall cover was pre-formed, difficulty was experienced in reliably preventing braze leakage into the waveguide interior. This manifested itself in increased loss.

The first attempt at improvement was based on available components. The block and cover were drilled and tapped along the cover edge and .001" gold foil was compressed between the two parts. Figure 1 shows the results obtained. The loss was reasonable but about 0.5 db above what was expected. When tested with the fused mica window assembly the loss hovered between 1.2 and 2.2 db. Difficulty was experienced with keeping the thin foil intact in the presence of a slidable plunger. Thus it was decided to electroform the input waveguide as had always been done with the output waveguide.

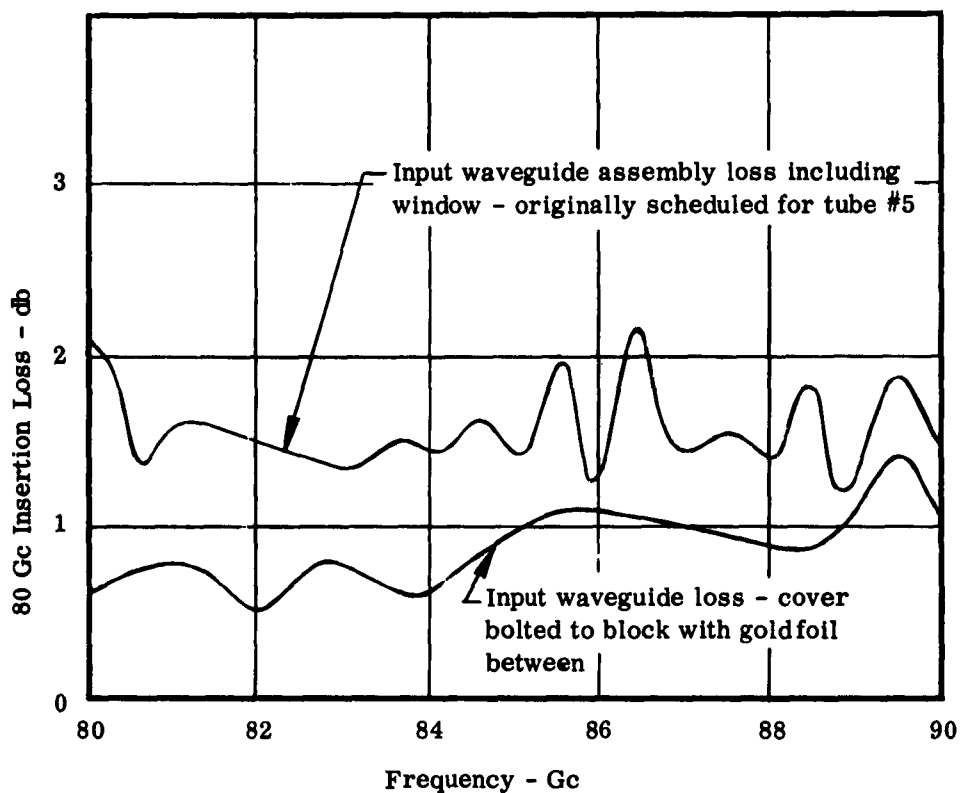
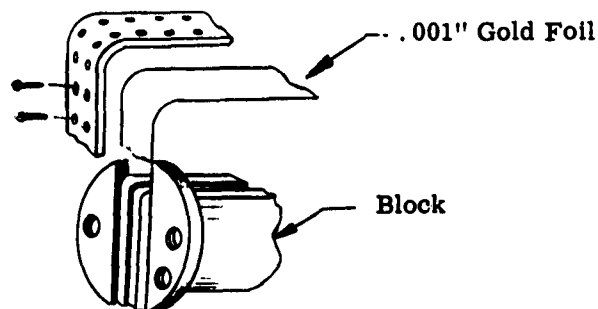


Fig. 1 - The above measurements are of input waveguides machined in the helix - wedge support block. In each case the waveguide cover was bolted on with .001" gold strip between. The losses are objectionably high.

Figure 2 provides data on an output waveguide section and it is to be noted that the loss is essentially below 0.5 db for a typical plunger fit. Note the power loss from a loose fitting plunger - some units have shown regions of 3-4 db loss from poor contacts. Of course, it is ideal to solder the plunger in place, but the finality of the operation hinders its utilization.

Figure 3 shows that the (flange-to-plunger) waveguide-window assembly loss can be held below 0.5 db with reasonable care. This output waveguide incorporated a good fitting plunger and a compression seal mica window. This assembly was prepared for tube No. 5. The input waveguides (now made similarly) exhibit 0.1 to 0.2 db additional loss due to extra length.

Waveguide Window Improvement

The fused mica window was not reliable as to loss, and could not be replaced without endangering the entire tube. Thus a switch was made to the Lindsey¹ - type mica compression window. The axial dimensions are as proposed by Lindsey except for a reduction in depth of the recess in the backing flange. In-plant experience dictated that the molybdenum washer extend .001" beyond the waveguide-face to assure a proper seal throughout bakeout. The microwave loss for the design is but 0.1 or 0.2 db for properly mating parts.

Waveguide-To-Helix Coupling

Problems Noted

Tube No. 3's low net gain of -30 db was attributed mainly to poor waveguide-to-helix coupling. An attempt was made to reduce the 50-70 db cold insertion loss of tube No. 3, through a port-hole blown in its glass envelope. The helix was moved axially to no avail while noting radiation and insertion loss. It was evident that most of the waveguide-to-waveguide coupling came from radiation and reflection, rather than circuit dissipative loss.

Subsequent tests were made on various helix assemblies to determine the magnitude of the coupling loss.

The procedure utilized was to drive a .003" or .004" wire through the helix and plot reflected power from the waveguide to helix junction as a function of the distance between the junction and the end of the wire (effectively a short).

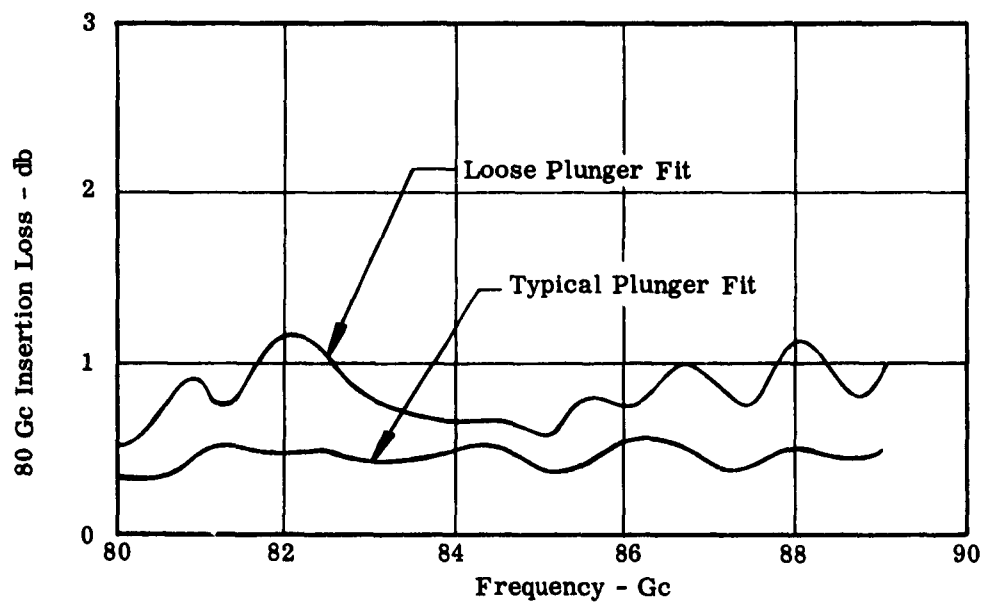
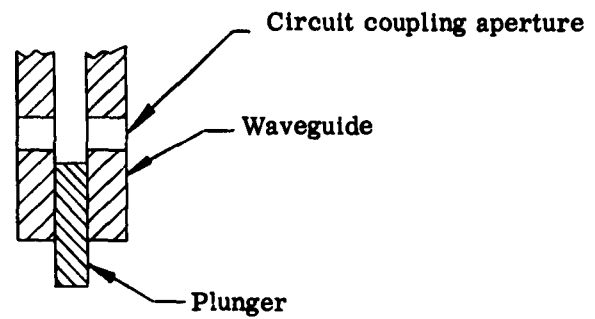


Fig. 2 - The above measurements show the importance of good plunger contact. One half decibel extra loss corresponds to about 10 percent power loss at the plunger.

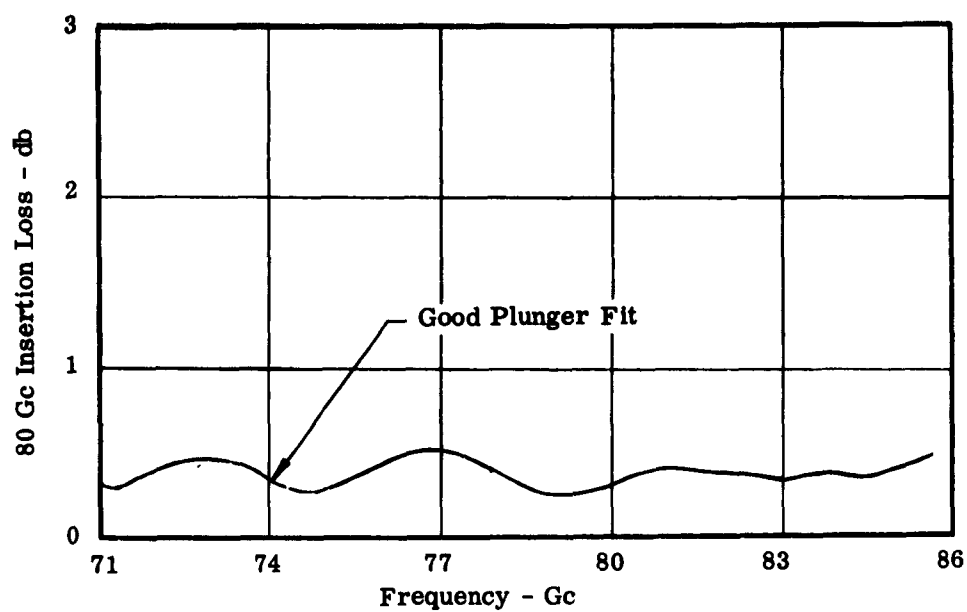


Fig. 3 - This is the loss of the output waveguide - window assembly-of-tube No. 5. The total loss from flange-to-plunger including the compression seal window is below 0.5 db.

Figure 4 shows the results of one of these tests. The dotted curve, the locus of the maximum voltage reflection coefficients, has an asymptote at 8.5 percent reflection coefficient. For calculation of loss it was assumed that the assembly contained two mismatches, one at helix-waveguide junction and the other at the wire short. These add or subtract according to the phase of the mismatches. The resultant maximum VSWR is the product of the VSWR of the junction with that of the effective VSWR of the short at the junction (as modified by the coupling and helix loss). Working backwards from the change in VSWR as the short is moved, the shorts' effective VSWR is deduced, from which the attenuative padding and waveguide to circuit coupling is determined. The loss should be linear vs distance, with the helix-to-waveguide coupling appearing as the Y-axis intercept at zero helix-entrance to short separation. The calculated loss showed a slope of 33 db/inch with an apparent 12 db coupling loss. Such a high coupling loss could only mean severe radiation. This might explain the sharp change in slope as the wire short enters the waveguides coupling slot, where it apparently reduces the magnitude of the radiation.

This assembly was similar to others tested showing in general a 10-12 db waveguide to helix coupling loss and .45 db/ λ_g circuit loss.

Although "real" match had been achieved originally with this configuration, it had led to the failure of tube No. 3, and would continue to produce questionable results unless modified. The big question in a match of this sort (wherein the wedge protrudes into the guide for helix support) is the effect of the wedge. One would suspect that filling the slot (0.2 x guide width) with material of dielectric constant, 9, would increase the effective slot size to 0.6 x guide width, making the slot an effective radiator. Data on this effect is shown in Fig. 5. The wedge supported helix was slid into the slot while a fixed detector probe recorded the change in radiated power at a point 0.25" from the slot, just above the back edge of the wedge. The power radiated in the absence of the circuit is approximately 36 db below that incident to the waveguide. As the wedge approaches the slot it deflects some of the power, reducing the amount reaching the probe. As the dielectric enters the slot the radiation, or perhaps to some extent transmission via the dielectric, increases substantially to a level 20 db higher than from the open slot. The power reaching the detector did not change drastically as the wedge moved though the position showing a good match. Thus in this case one could conclude that power did indeed couple to the helix (or was sent another direction) without materially affecting that radiated to the fixed probe.

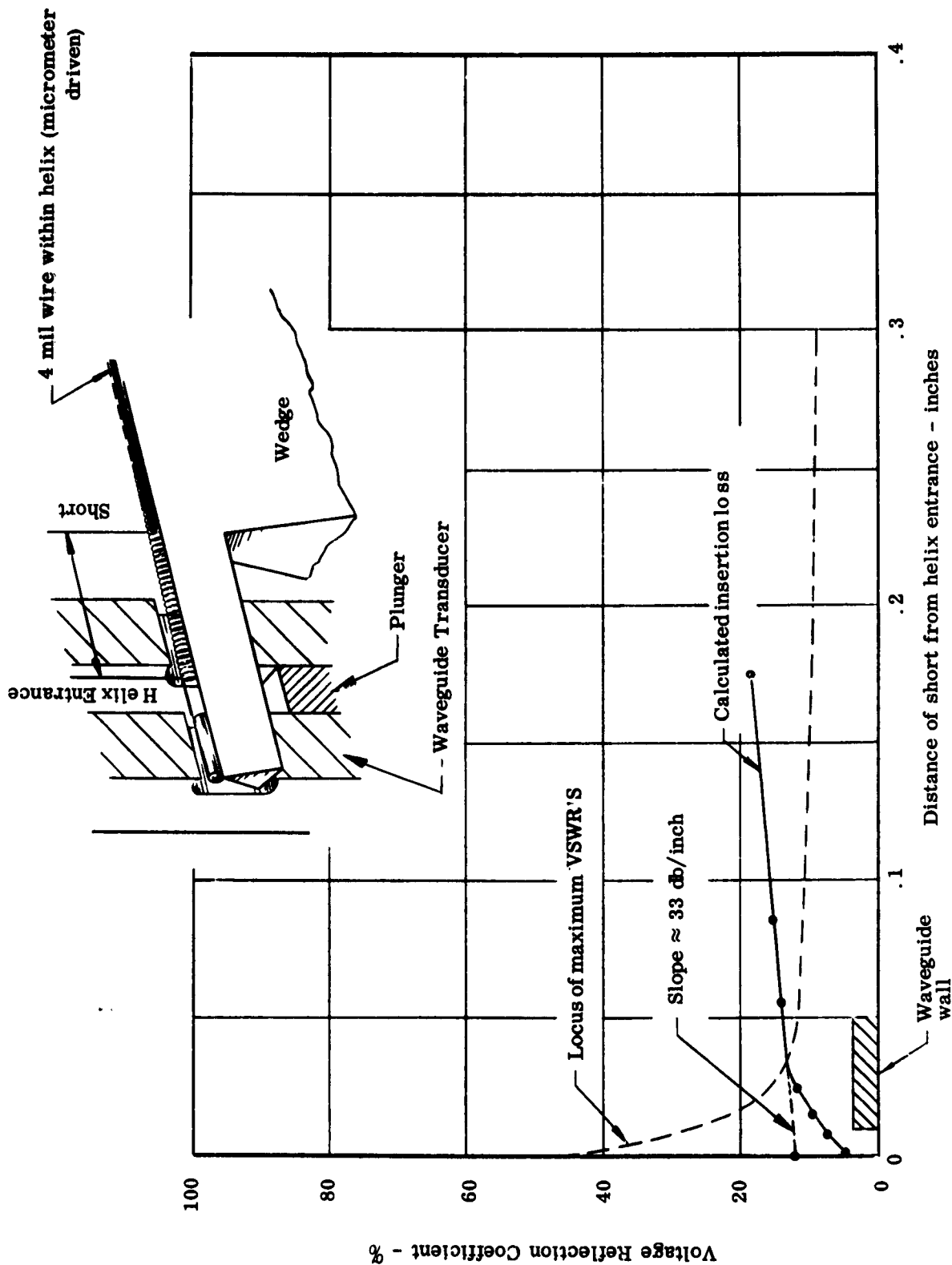


Fig. 4 - A micrometer-driven wire within a wedge supported helix was used to verify high waveguide-to-helix coupling loss and dissipative helix loss. The "wedge insertion" type of match led to the poor results of tube #3.

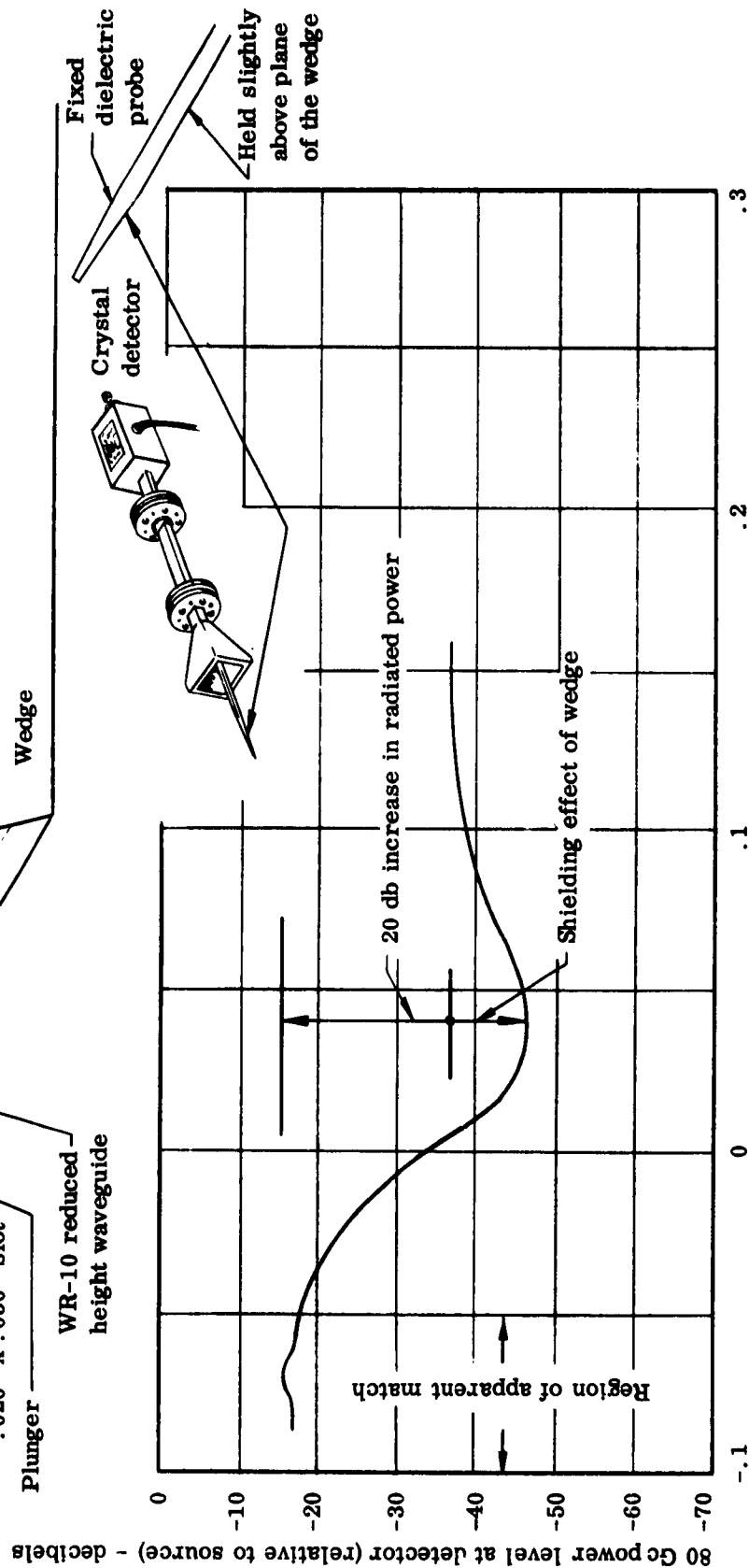


Fig. 5 - The power radiated from the waveguide slot increases substantially with the intrusion of the dielectric. With power radiating at this magnitude it is not hard to visualize direct waveguide coupling to-waveguide coupling in the order of 40 decibels.

Match Improvement

In order to obtain a reliable match it was necessary to eliminate wedge intrusion into the waveguide. To facilitate measurements, copper-plated helices were laid in low loss capillary tubing.

A series of tests were made from 70-90 Gc with probe antenna of various lengths, the most satisfactory being .09". Figure 6 is a repeat of Fig. 5 with the optimum capillary tubing supported helix assembly. The radiation level (compared to Fig. 5) is about 20 db less without helix and 34 db less during match. The VSWR was in the order of 1.5 and the waveguide-to-waveguide transmitted power down about 30 db, corresponding to .26 db/ λ_g . The match was judged satisfactory. The next step was to repeat it with wedge-support of the helix.

A judgement was made that an assembly wherein the helix overhung the wedge .04 to .05" was impractical because of sag (overhang required to keep wedge external). Capillary tubing extensions of the wedge also looked too difficult to attempt at the time. Thus several helix-wedge assemblies were tested wherein the probe antenna was in the order of .135". The match, at best, was only fair and severe radiation was again present. Just about this time, Stuart Leaf, returned from a project-sponsored-trip to BTL, Murray Hill, New Jersey. He reported that the BTL engineers working on the 50-60 Gc traveling-wave amplifier used the identical match wherein a "pig-tail" probe was pulled from the wedge supported helix. They use full height guide and their probe antenna reaches to the guide center. No significance is attached to these variations but their procedure of cutting away the waveguide wall until the coupling aperture is but 0.3 times the normal length looked promising to try. This was tried and it did improve the match, however radiation measurements still showed a 20 db increase in radiated power as the assembly was inserted into the waveguide. Although the match appeared real, means of shielding the helix from the return of reflected radiations would need to be incorporated (as is presently done in the BTL amplifier).

A safer approach would be to put the helix in the waveguide aperture, perhaps slightly within the guide itself (with coupling antenna). This procedure insures proper launching of the wave onto the helix, and with gradual removal of the aperture wall, the energy should not appreciably radiate. This, it will be recalled, is the location empirically found with the helix supported in capillary tubing and also when the helix, antenna and shorting cylinder were glazed to the wedge. Several assemblies were made terminating with a .05" helix overhang and .05" probe antenna.

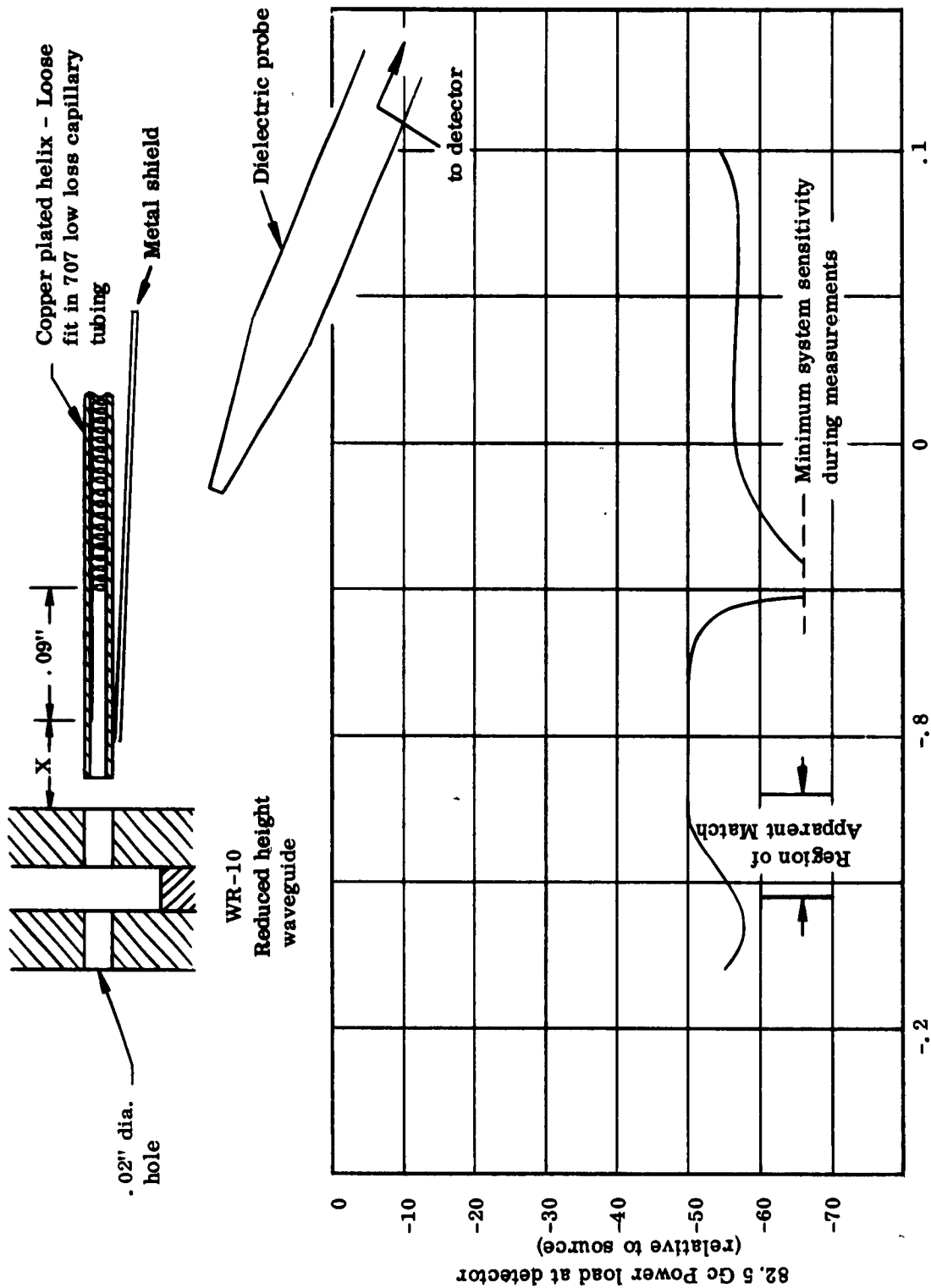


Fig. 6 - The probe type revision to the wedge match shows a 34 db reduction in radiated power relative to the data of Fig. 5. The helix loss recorded above was .26 db/ λ g.

The match, radiation level, and transmission were found to be excellent, equivalent in all respects to that obtained with the helix supported in capillary tubing. In fact, transmission losses (for the wedge supported circuit) below 40 db were measured for the very first time. Figure 7 shows the match configuration and the excellent results obtained. Match < 1.6 over most of the band, and $.375 \text{ db}/\lambda_g$ were noted. Verification of good coupling shortly followed. A thin molybdenum sheet was inserted between the helix turns at successive distances from the input. Data obtained by means of this movable short are shown in Fig. 8. The loss shown includes 1.1 db from the waveguide coupler and a connecting waveguide. The coupling loss noted is between 0-2 db. Engineering judgement, considering the experimental error, would indicate negligible coupling loss. The probe match was easily repeatable, and found highly reliable.

Circuit Dissipative Loss

The circuit loss could be determined and improved now that a reliable waveguide-to-helix coupling was available. The $.375 \text{ db}/\lambda_g$ noted was much higher than the $0.2 \text{ db}/\lambda_g$ design value, but acceptable to try in a tube.

Two more helices were readied for this purpose, but had 10 db more loss than the 36 to 43 db noted. This result further postponed the fabrication of tube No. 5 and commenced the final phase of the loss improvement program. The starting point in Fig. 9 is the data from Fig. 8. A wedge (No. 2) was sprayed very light ($.0005''$ glaze thickness). After firing, the helix bond was only slight but the loss still high. The circuits in both cases were plated to 30 micro-inches thickness after glazing. It had previously been determined that glazing to the pre-plated helices at 1050°C produced either lossy lateral crackings or the growth of grain boundaries, visible only at microscopic powers beyond 100 x. The reported plating thicknesses are several times the ten micro-inch skin depth. The thicknesses reported could be in appreciable error since the only method found practical is to calculate them from the change in over-all helix resistance caused by the plating.

A second plate (No. 3) to 60 micro-inches reduced the loss about 5 percent, and sintering at 700°C (No. 4) provided another 9 percent improvement. A cycled plating was tried (No. 5) with a 4:1 "forward-to-reverse" time ratio with perhaps a slight improvement over the uni-directional plating (No. 3). A repeat of the cycled plating followed by sintering (No. 6) produced the best results (with the high temperature glaze). Repetition of this procedure with adequate glaze (for bonding purposes) put the loss again in the $.4$ to $.45 \text{ db}/\lambda_g$ class again (No. 7 and 8).

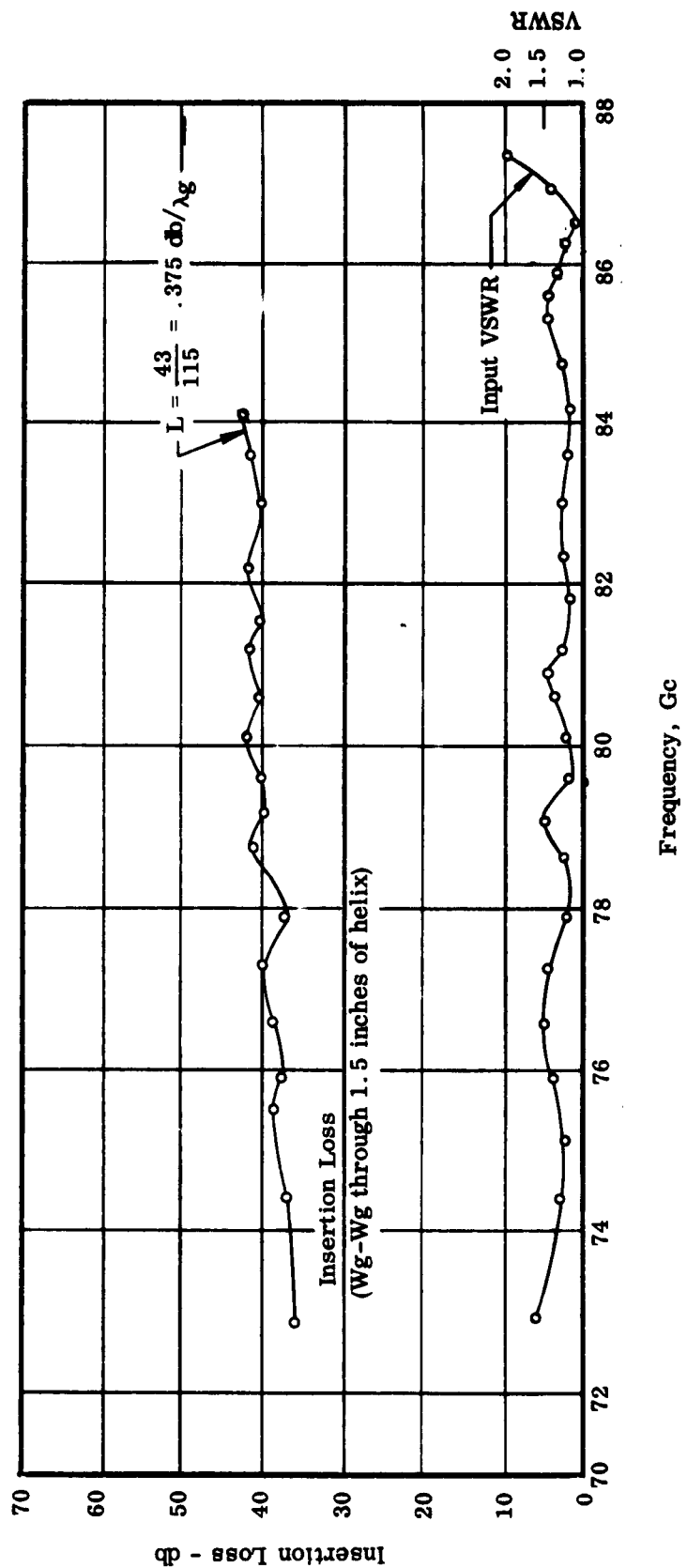
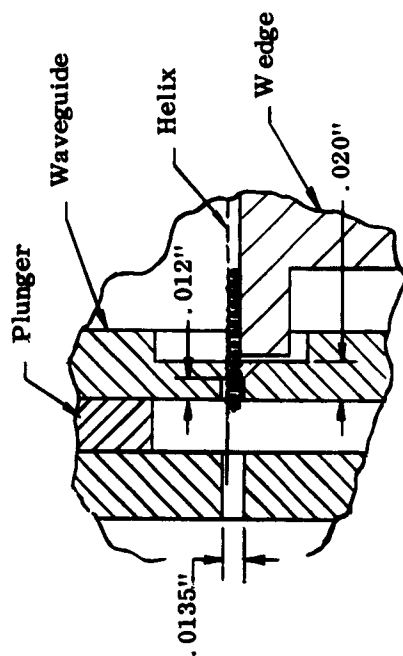


Fig. 7 - The (non-contacting) probe match provides reliable waveguide to circuit coupling. The wedge supported helix was glazed with the high temperature M24C mixture, followed by copper plating.

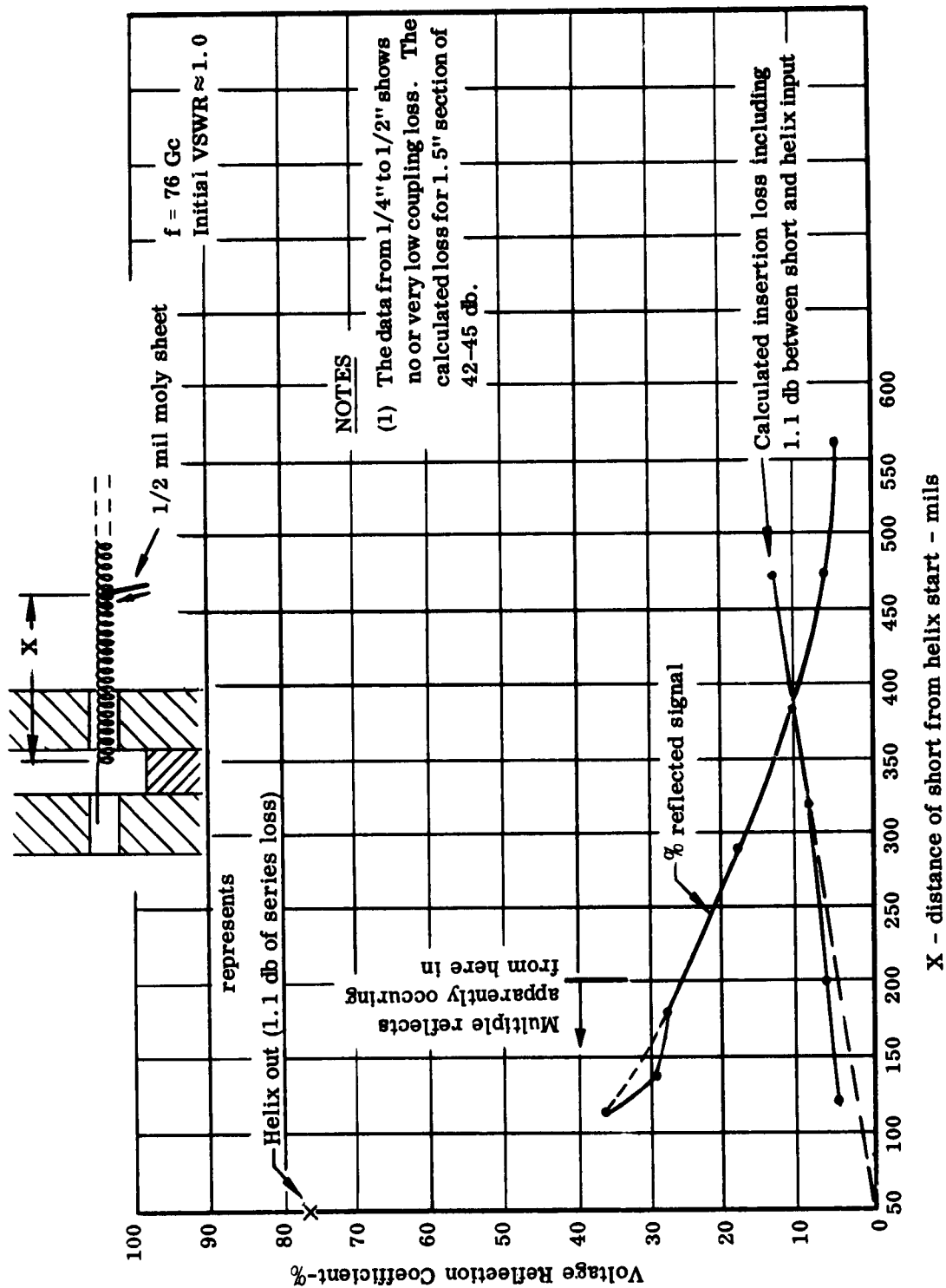


Fig. 8 - The match of Fig. 7 was checked for waveguide to helix coupling by successively placing a short at various distances from the helix entrance. It appears excellent, probably negligible.

Helix Insertion Loss - db				Helix Plate			Type of Bond			Helix-Wedge Glaze		Time Min	Date 1962	Assy #											
20	30	40	50	First μ inch	Second μ inch	Sinter $^{\circ}\text{C}$	Light	Med	Hvy	Atmosphere	Temp $^{\circ}\text{C}$														
M24C Glaze				Inadequate Bonding											A30				✓	✓	H ₂	1050	10	10-9	1
															A30			✓			H ₂	1050	10	10-24	2
																A60		✓			-	-		10-24	3
																A60	700	✓			-	-	-	10-24	4
																A50 cycled		✓			-	-	-	10-25	5
																A60 cycled	700	✓			-	-	-	10-25	6
Pyrocram Glaze				Inadequate Bonding											A50		700		✓		H ₂	1050	10	10-26	7
															A50		700		✓		H ₂	1050	10	10-29	8
															A60			✓			H ₂	750	60	11-1	9
																	700	✓			-	-	-	11-1	10
															B60			✓			H ₂	750	60	11-1	11
															B60			✓			H ₂	750	60	11-1	12
															B60					✓ (4)	N ₂ -cooled in H ₂	750	60	11-13	13
															B60					✓ (4)	"	750	60	11-13	14
															B60				✓ (3)		"	750	60	11-15	15
															B60				✓ (2.5)		"	750	60	11-15	16
Less Glaze																									
Ok																									

NOTES:

(1) $f = 73$ to 86 Gc (2) "A" or "B" refers to the time of plating relative to glazing, eg. A30 means 30μ inches of Cu plating applied after glazing. (3) The low-temp glaze is pyrocera cement # 45. The high-temp glaze is the std WJ helix glaze, M24C (4) The numbers in parenthesis in the "Type of bond" column represent spray jig opening in mils. (5) The 1.5" helix contains about 115 guide wavelengths at 80 Gc.

Fig. 9 - Compilation of results of circuit loss reduction program.

A real break-through occurred through the utilization of Corning Pyroceram No. 45 glaze. The first try (No. 9) produced loss of only .28 db/ λ g but the lack of proper fillets resulted in inadequate bonding. In this case (No. 10) sintering did not materially help as would be suspected.

Since glazing occurs at 750°C, the wedge can be glazed to copper plated helices without the danger of developing plating cracks.

Assemblies No. 11 and 12, made in this fashion showed slightly improved results, .27 db/ λ g, but in each case (9 through 12) the bonding was inadequate for mechanical support of the helix.

It was thought the bonding could be improved if a slight oxide film could be formed. Therefore, the glazing environment was changed to nitrogen. The small trace of oxygen present was sufficient to provide heavy bonding (No. 13). Cooling in hydrogen removed the excess oxide. Next the amount of glaze was successively reduced via the spraying operation (No. 14, 15 and 16). Assembly No. 16 was put in tube No. 5. It had adequate bonding with .32 db/ λ g.

In retro-spect the low temperature glaze is superior since it does not harm the circuit plating and because its loss qualities are better than those of the higher temperature glaze (which is equivalent to alumina silicate). A compromise between bond strength and circuit loss is required regardless of the loss. Further improvement might lie in improvement of the bonding without resorting to oxidation.

Prognosis of Tube No. 5

Excellent progress has been made since tube No. 3 (which had 30 to 40 db loss). As noted the problem for that tube was diagnosed as poor waveguide to helix coupling, high power radiation and excess helix dissipative loss.

Tube No. 5 at first showed 80 Gc gain in excess of five decibels (first few minutes of test), then grew progressively worse, netting but minus five decibels at design current (70% transmission) just before dismantling. Electrical tests coupled with visual observations (through the glass envelope) indicated the following:

1. Internal arcing between cathode cup and anodes 7 and 8 (2500 volt separation) resulted from an assembly error in lead orientation. The arc could only be eliminated by strapping anodes 4-8 and keeping their potential below 1000 volts.

This, in turn, resulted in a severe last-anode to circuit voltage jump. The beam could then only be focused via a critical combination of electrostatic potential and magnetic field adjustment.

2. The revised match while excellent electrically has one important limitation. Part of the helix is hung off the wedge to avoid opening the coupling waveguide aperture with a dielectric. Unfortunately, the poor transmission resulted in overheating at these unsupported ends (poor heat drain). From visual observation it could be seen that the copper plating on these sections had vaporized or melted.
3. Subsequent checks on the tubes' input and output match showed they had risen from a broadband 1.5:1 to slightly periodic values in excess of 3:1 from 70-85 Gc. Helix or plunger movements were not strongly suspected in the presence of the known copper migration, particularly when parallel tests indicated that relative helix to waveguide movement injects a severe periodicity to the match characteristic. On the other hand, these side tests showed that the general match was severely degraded if the helix antenna contacted the waveguide. Thus, the primary suspicion was an antenna-to-waveguide short, or turn bridging by melted plating.
4. Throughout the test, there was no indication of helix current, yet the beam could be synchronized with the circuit wave via the helix voltage. It was thus deduced that the helix contact was made elsewhere. The only logical point would be helix-antenna to waveguide contact. This was assumed to occur at the output since it could not be re-verified visually that "plating vaporization at the output" was indeed true. Without calculation it was assumed that a helix antenna contact to the massive block would have adequately cooled the overhung helix.

The gain was considered too low for noise figure evaluation so the tube was carefully dismantled showing the following:

1. The normal helix contact was open - contact was made where the output antenna shorted to the output waveguide.
2. Both ends of the helix, at the non-wedge supported segments, had deteriorized plating. The input end plating had primarily vaporized, but at the output the copper had melted enough to bridge many turns - looked like a miniature random ring bar circuit. The top of the output antenna ended in a large globule (about 3 mils in diameter).

3. In cold test, prior to tube assembly, a 25 turn segment of helix had been accidentally pulled loose from its glaze, but had sprung back to position. This section was also gutted with a dozen turn-bridgings.

Comparison of Measurement with the Gain Calculated

Of course, the inability to reach .2 db/ λ_g loss reduces the expectant gain. At 80 Gc, the .32 db/ λ_g loss for the 1.575" helix of (tube No. 5) should provide 17.6 db gain at the design 80 μ a. The expected gain of this tube could be lower by almost 10 db, if each of the following detriments were in action:

1. Total internal window, waveguide, and helix coupling losses - should be less than 1 db, but could be as high as 2 db somewhere in the band (70-85 Gc).
2. Since only the wedge - supported helix can be certain of synchronous action, the contribution of the .07" of helix over-hanging the wedge should be ignored. This will lower the gain a maximum of 1.3 db.
3. The "dead" helix also adds loss to the signal in coupling - $\frac{.07}{.015} \times .32 \text{ db}/\lambda_g$
= 1.45 db if plated, and 2.9 db if not plated.
4. The helix connection produced unexpectedly high cold loss - about 15-20 db over one guide wavelength - thus it would appear as a "sever" of short "CN", and should reduce the gain 4 db.

The minimum gain expected from tube No. 5, at the design current would then be 17.6 - (2 + 1.45 + 1.3 + 4) = 8.85 db \approx 9 db. In the first few minutes of test gain in excess of 5 db, was noted however at last test the gain was - 4db (slightly positive gain could be obtained by careful focusing at much higher cathode currents).

Thus, at the conclusion of the recent tests, the actual gain was 13.4 db below the minimum expected. Since the plating was vaporized from the extended input portion of the helix we can account for an additional .7 db if this section were at room temperature. Beam interception vaporized the plating so this section's temperature must exceed 800°C. If one assumed the insertion loss increased in proportion to the square root of the dc resistance, the loss of the unplated input helix would change from 1.45 db to 3.2 db. Reflections at the two segments of bridged turns must be severe. If it is assumed they act as severs the effective gain reduction would be 4 db per sever.

What Gain Is Expected Under These Conditions?

$$17.6 - \underset{\substack{\uparrow \\ (1)}}{2} + 3 \times \underset{\substack{\uparrow \\ (2)}}{4} + \underset{\substack{\uparrow \\ (3)}}{3} + \underset{\substack{\uparrow \\ (4)}}{3.2} + \underset{\substack{\uparrow \\ (5)}}{1.8} = -4.4 \text{ db}$$

1. Max. tube loss external to helix.
2. Three severs (incl. attn).
3. Loss in active length by 3 severs + input helix overhang.
4. Unplated helix input at 800°C acts to lower signal input.
5. Reflected power at tube input from antenna to waveguide short producing a 3.8 VSWR.

In other words, while these calculations cannot be exact, they do indicate that the measured gain is that calculated.

Tube Improvements Planned

The circuit should be lengthened or the cathode diameter be increased to get more gain margin to make up for the inability to achieve low enough circuit loss, and the gain lowering effects of the revised match and helix contact. A longer helix requires longer wedges and block. The minimum delivery is 4 weeks. Working out "bugs" and making the first tube would take another month. This step is planned immediately for insurance. (Admittedly, it would be ideal to keep the cathode-helix length at 3", to almost directly use an available 2000 gauss magnet.) The desired gain, taking all likely detriments at their worst, should be 30 db, which in turn is 10 db above contract commitments. Assuming the worst (that is, the gain detriments remain at 9 db) than a 2.65" active helix will provide 30 db tube gain at the 80 μ a design current. This will add about 1" to the required focusing field.

In the interim our next tube will incorporate a larger cathode, either 2.3 or 2.8 mils, depending upon their performance in diodes. Operated at the same current density, the available current becomes 106 and 157 μ a, respectively. The 2.8 mil cathode should raise the gain ten decibels to 27.6 db (or 18.6 db, if misc. losses are not reduced).

An attempt will be made to contact the helix with the input waveguide at the antenna, without disturbing the match. This could gain 4 db. A reduction in the overhung helix to the minimum could pick up another db. A .006" beam aperture will be added prior to the input waveguide to reduce the possibility of beam interception on the extended helix at the input. Similarly a 35 millisecond (response time) helix current overload has been installed on the test power supply. This circuitry is adjustable to any desired helix current to trip the anode voltage.

Further tests are planned to improve both the thermal and microwave properties of the circuit.

Comparison of Measured and Calculated Gain vs $I_c^{1/3}$

Figure 10 is a plot of measured and calculated gain as a function of $I_c^{1/3}$. Note the similarity of the so called asymptote to the slope of the calculated gain. This means that the circuit beam interaction is proper.

Circuit Contact

The probe match while providing excellent signal coupling was non-contacting in the form used on tube No. 5. Helix contact was made through aquadag painted on the wedge. The aquadag layer was tapered to .015" at helix contact. Spring contact was made to the aquadag for the helix connection.

The contact raised the insertion loss about 15 db, hence effectively producing a circuit sever to the mm signal on the helix. This could produce a 4 db gain degradation. To avoid this loss efforts are underway to change to a contacting match. C-band components were made to facilitate the change. The scaling used was to increase all dimensions by the ratio of the C-band to WR-10 waveguide widths (13.72). As noted in Fig. 11, the C-band version of the tube, seems immense relative to the mm components. The micro-manipulator test jig in the foreground allows relative waveguide to circuit positioning of the millimeter components while hand locating is adequate for the scaled components. The scaled helix is attached to the ceramic wedge with acroloid. The unplated circuit loss is very low (only .12 db/ λ_g) in the 5-9 Gc frequency range. The helix-antenna-sleeve combination shown in Fig. 11 provided excellent match. The sleeve is secured in the waveguide with the waveguide wall screw. Figure 12 shows the effect of three versions of the match, the best of which is below 1.5:1 VSWR from 5.4 to 8.2 Gc. The millimeter frequency equivalent of this is 74 to 112 Gc. The low frequency match deteriorates since the operating frequency is too close to the waveguide cutoff frequency.

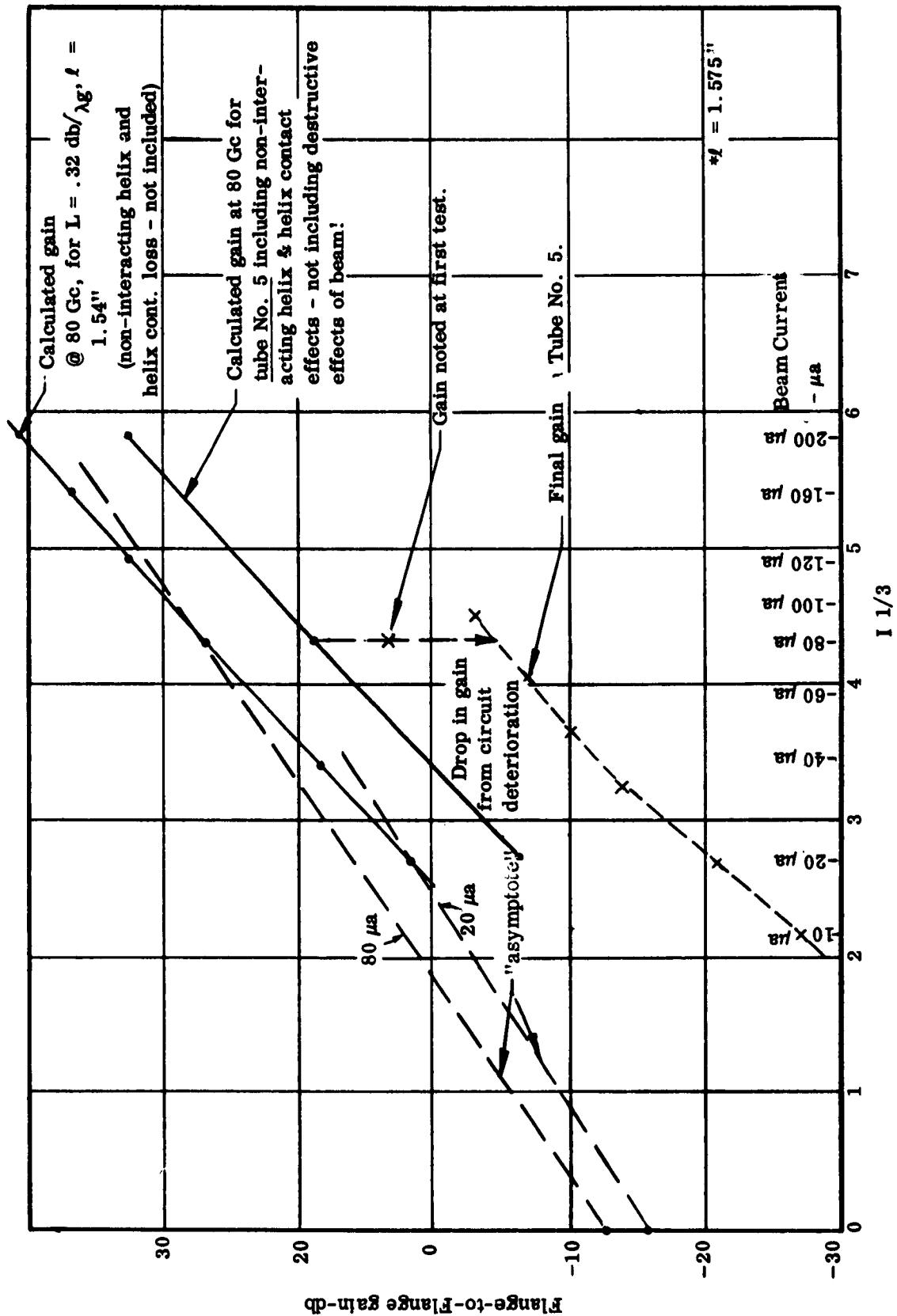


Fig. 10 - The gain vs $I^{1/3}$ of Tube No. 5 is similar in slope to that calculated. This indicates that the circuit-to-beam interaction is as predicted.

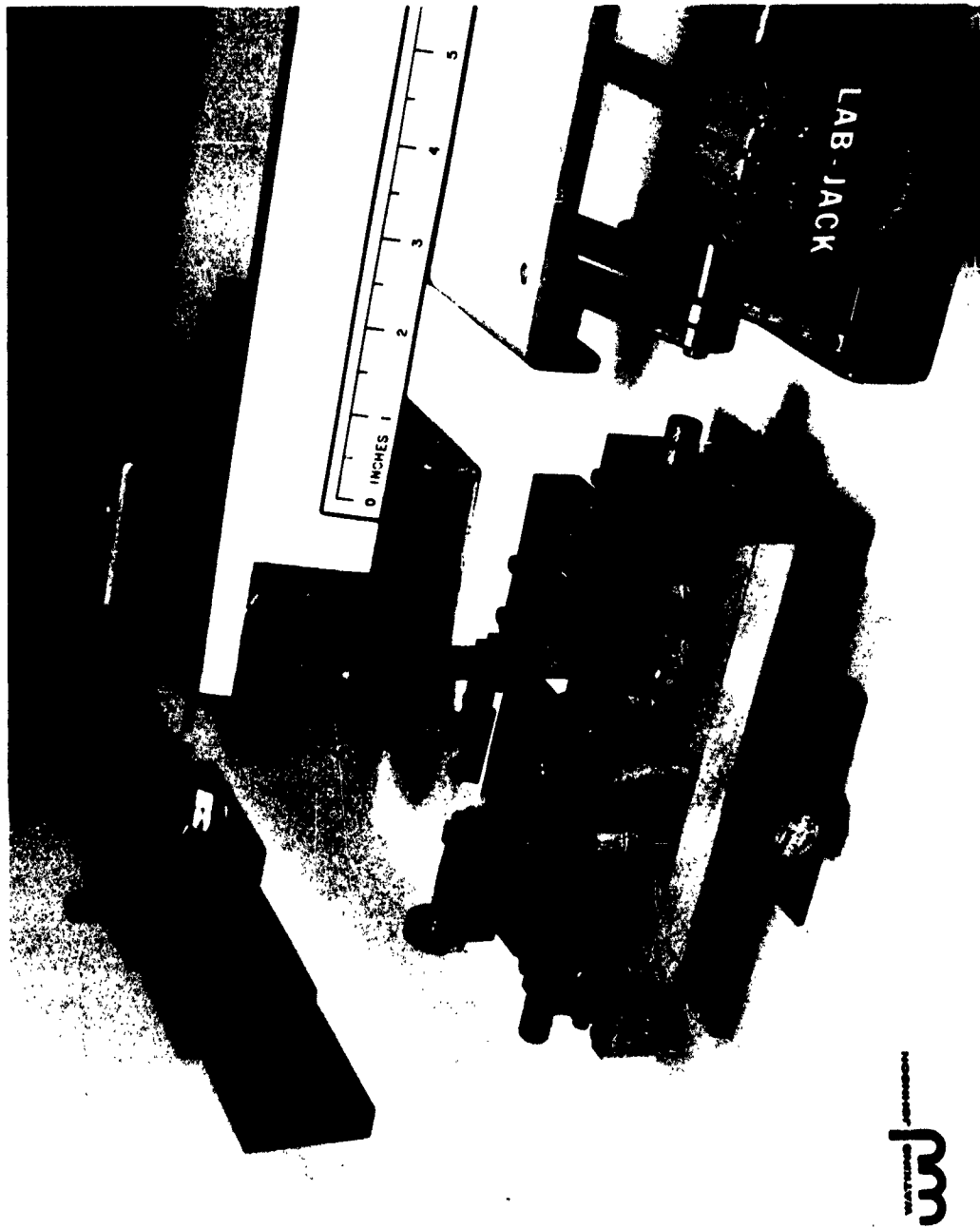
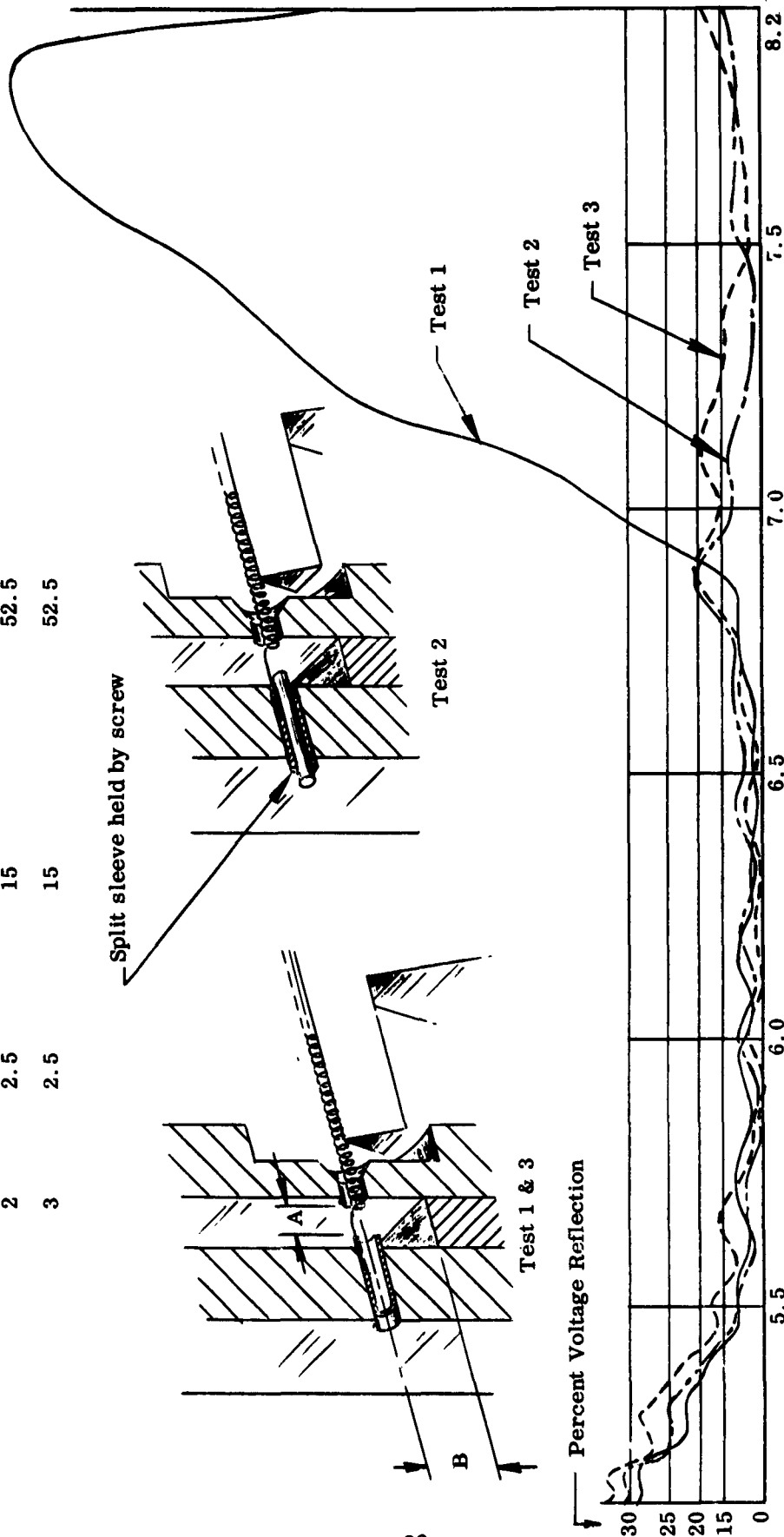


Fig. 11 - The mm circuit and waveguide components are shown in Comparison to the scaled C-band cold test components. This shorted probe match provided excellent match over the majority of the required band. The unplated circuit loss was but .12 db/ λ_g at C-band.

Helix Turns Antenna Length Helix-to-Plunger Separation
Within Guide (A) - Mils (B) - Mils

Test	1	2	3
Helix Turns Within Guide	2.5	2.5	2.5
Antenna Length (A) - Mils	29	15	15
Helix-to-Plunger Separation (B) - Mils	65.7	52.5	52.5



Percent Voltage Reflection

Frequency in Gc

Fig. 12 - The scaled C-band components were used to develop a shorted probe match with VSWR < 1.5:1 at frequencies equivalent to 74 to 112 Gc (13.72 scaling factor.)

Modification to ridge or slightly wider guide will solve this problem. These components were duplicated at the millimeter frequencies and performed very well. Figure 13 shows the millimeter match obtained. It is seem to be below 2:1 from 71 to 89 Gc.

This seemingly simple revision to the match has proven exceedingly difficult to fabricate reliably.

If at all possible this version or some modification of it will be incorporated in the next tube.

CONCLUSIONS

1. Five decibel flange-to-flange gain in the 80-85 Gc range was achieved.
2. The circuit to beam coupling is as predicted.
3. Low loss waveguide to helix coupling has been achieved in several forms.
4. Helix insertion loss is reproducible in the order of .3 db/ λ_g ; waveguide and window losses have been reduced to the order of 0.5 db.
5. As reported in detail under AF 30(602)-2422, tests have shown cathode emission at 3-4 a/cm² which improved through 1500 hours of life test, indicating no life problems from this source.

PROGRAM FOR THE NEXT INTERVAL

Build several tubes with gain adequate for noise figure evaluation

IDENTIFICATION OF PERSONNEL

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* Resume Included

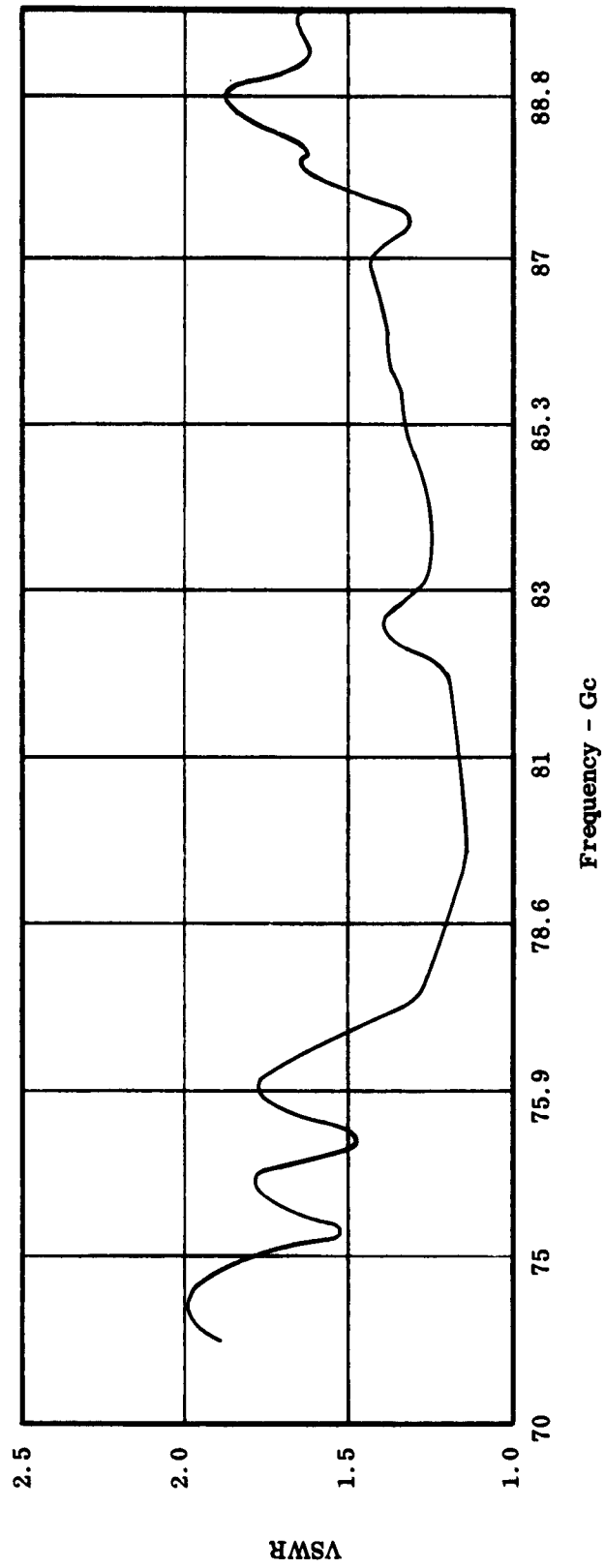


Fig. 13 - The shorted probe match was repeated with mm frequencies and with only a waveguide to circuit positioning change provided good broadband match.

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